Exhibit M

Published in final edited form as:
Int J Obes (Lond). 2012 October ; 36(10): 1261–1269. doi:10.1038/ijo.2012.95.

Ethnic and sex differences in body fat and visceral and subcutaneous adiposity in children and adolescents

AE Staiano and **PT Katzmarzyk**
Population Science, Pennington Biomedical Research Center, Baton Rouge, LA, USA

Abstract

Body fat and the specific depot where adipose tissue (AT) is stored can contribute to cardiometabolic health risks in children and adolescents. Imaging procedures including magnetic resonance imaging and computed tomography allow for the exploration of individual and group differences in pediatric adiposity. This review examines the variation in pediatric total body fat (TBF), visceral AT (VAT) and subcutaneous AT (SAT) due to age, sex, maturational status and ethnicity. TBF, VAT and SAT typically increase as a child ages, though different trends emerge. Girls tend to accumulate more TBF and SAT during and after puberty, depositing fat preferentially in the gynoid and extremity regions. In contrast, pubertal and postpubertal boys tend to deposit more fat in the abdominal region, particularly in the VAT depot. Sexual maturation significantly influences TBF, VAT and SAT. Ethnic differences in TBF are mixed. VAT tends to be higher in white and Hispanic youth, whereas SAT is typically higher in African American youth. Asian youth typically have less gynoid fat but more VAT than whites. Obesity per se may attenuate sex and ethnic differences. Particular health risks are associated with high amounts of TBF, VAT and SAT, including insulin resistance, hepatic steatosis, metabolic syndrome and hypertension. These risks are affected by genetic, biological and lifestyle factors including physical activity, nutrition and stress. Synthesizing evidence is difficult as there is no consistent methodology or definition to estimate and define depot-specific adiposity, and many analyses compare SAT and VAT without controlling for TBF. Future research should include longitudinal examinations of adiposity changes over time in representative samples of youth to make generalizations to the entire pediatric population and examine variation in organ-specific body fat.

Keywords

pediatric; body fat; visceral adipose tissue; subcutaneous adipose tissue; ethnic differences; sex differences

Correspondence: Dr PT Katzmarzyk, Population Science, Pennington Biomedical Research, Center, 6400 Perkins Road, Baton Rouge, LA 70808-4124, USA., Peter.Katzmarzyk@pbrc.edu.

CONFLICT OF INTEREST
The authors declare no conflict of interest.

INTRODUCTION

Pediatric obesity contributes to physical and emotional health problems during childhood[1] and leads to future co-morbidities and premature mortality in adulthood.[2] Health consequences associated with obesity differ based on where adipose tissue (AT) is stored, for instance subcutaneously between the skin and muscle versus internally, such as within the chest, abdomen and pelvis (visceral AT (VAT)) or within and between muscles (nonvisceral AT).[3] Recent advances in body composition imaging allow for the examination of specific depots of AT in the pediatric population, providing sufficient precision to evaluate individual and group differences. Although the terms body fat and AT are often used interchangeably, fat specifically refers to lipids in the form of triglycerides, located mostly in AT though also present in other tissues of the body.[3] Dual-energy X-ray absorptiometry (DXA) is the method most commonly used to quantify total body fat (TBF) *in vivo*.

AT is loose connective tissue replete with adipocytes.[3] Its chief functions are energy storage, thermal insulation and mechanical cushioning. AT is composed of 80% fat but also includes protein, minerals and water.[4] Total AT is subdivided into subcutaneous AT (SAT) and internal AT (IAT).[3] The major contributor to IAT is VAT, which is located beneath the abdominal muscles and is particularly linked to poor cardiometabolic outcomes in youth.[5,6] To measure total AT as well as AT stored in specific organs and regions, the gold standards are magnetic resonance imaging (MRI) and computed tomography (CT). MRI is favored for the measurement of AT in children because, unlike CT, it uses a magnet and does not emit radiation.[7] We primarily focus on the depots of VAT and SAT, yet because the literature contains variation in the definitions used for each internal compartment,[3] we include IAT and intra-abdominal AT (IAAT) when VAT is not reported. IAT includes all AT other than SAT,[3] and IAAT includes AT within both the abdomen and pelvic region.[8]

Recent technological advances in biomedical imaging have transformed our understanding of pediatric obesity phenotypes in recent years. Thus, the purpose of this paper is to review the current status of our understanding about the extent of human variation observed in adiposity across the pediatric age range. Our focus is on the contributions of age, sex, maturation and ethnicity to variation in TBF, VAT and SAT. Further, we provide evidence of the link between adiposity and health outcomes where possible. Finally, we also discuss potential mechanisms including biological, lifestyle and environmental influences, challenges to measuring children's adiposity, and future research directions. Studies were preferentially included if the methodology employed MRI, CT or DXA. Studies using non-imaging techniques, such as anthropometry, hydrodensitometry or bioelectrical impedance methods, were included where image-based evidence was sparse.

INFLUENCE OF AGE

Total body fat

TBF accumulates as a child ages,[9] although inter-individual variation is evident as early as the third trimester of gestation. For example, MRI examination of 27 fetuses at 38–41 weeks of gestation demonstrated a range of 11.8–25%BF.[10] Thirteen of these babies born to

mothers with poorly controlled diabetes had higher birth weight and higher %BF (average of 27.4%) compared with the normal group, revealing early maternal influences on TBF.[10]

TBF also varies considerably during infancy: for instance, %BF estimated by MRI ranged from 13.3 to 22.6% in a group of eight white infants measured within 36 h of delivery.[11] Estimates from total body electrical conductivity demonstrated a sharp increase in %BF during the first 6 months of life and a slow decline thereafter in 423 healthy white infants (aged 14–379 days).[12]

After the first year of life, absolute TBF typically declines or stabilizes until 6 years of age.[13,14] A DXA study of the first 24 months of life found that %BF increased between 15 days and 6 months then decreased thereafter, although TBF increased with age.[15] At about 6 years of age, an 'adiposity rebound' occurs where TBF increases throughout the rest of childhood and into adolescence.[16] This rebound was confirmed in a growth curve analysis of CT scans that documented an average 2.0±0.9 kg per year increase in TBF throughout childhood between ages 8 and 13, adjusted for ethnicity, sex and baseline age.[17] When adjusted for total lean tissue mass, the increase in TBF remained significant at 1.9±0.8 kg per year, indicating that TBF accumulated faster than the growth of lean tissue.[17]

During the peripubertal and postpubertal periods, TBF tends to fluctuate within and among individuals. Trajectories established for 678 US children between the ages of 8 and 18 years, based on 12 observations over 4 years, revealed that TBF decreased as males aged, whereas TBF increased or remained constant in females.[18] The increase in TBF co-occurred with increases in body mass index (BMI) and abdominal circumference in both males and females. In a DXA study of 112 white girls tracked from ages 11 to 18 years, TBF gained was B6 kg.[19] Increase in %BF occurred between ages 11 and 12 and after age 16, whereas %BF decreased between 13.5 and 16 years.[19]

In an underwater weighing study, girls increased from 6.4 to 16.3 kg TBF and from 20 to 26%BF between the ages of 8 and 20, increasing constantly across the age range.[9] TBF growth was less consistent for boys and was inversely related to the increase in fat-free mass.[9] The increase of TBF persisted until about age 16 in girls and age 18 in boys, at which point it typically stabilized.[20] Similarly, in a sample of 8269 5–18-year-old children from the US National Health and Nutrition Examination Survey (NHANES), %BF based on skinfold thicknesses peaked at age 11 in boys but increased throughout childhood and adolescence for girls, resulting in a 1.5 times greater %BF in girls versus boys by age 18.[21]

Visceral adipose tissue

Young children deposit less than 10% of their AT in the IAAT depot, as observed in 12–14-year-olds.[8] Within the first month of life, IAT accounted for 10% of TBF in eight infants (within 36 h of delivery), yet most was deposited in the pelvis and limbs, not in the abdomen.[11] In fact, VAT was on average 0.03±0.01 l that comprised 33% of total IAT and just 0.7% of total body weight.[11] However, IAT may act as a protective fat layer in early infancy: 10 growth-restricted infants who had lower TBF, total SAT and abdominal SAT, still had similar levels of IAT compared with 25 normal weight newborns.[22] Similarly, VAT was higher in 2–6-year-old children born small-for-gestational age compared with normal

weight babies.[23] High levels of VAT can persist for several years: by age 6 years, VAT in small-for-gestational age babies was on average 50% higher than normal birth weight children.[24]

VAT increases with age throughout childhood (ages 5–17) and into adulthood.[25] In African American prepubertal 4–10-year-old children, the rate of change of IAAT was 4.3±1.6 cm^2 per year over 2 years.[26] A longitudinal study of 138 white and African American children aged 8 years at baseline and followed for 3–5 years found that VAT grew on average 11.6±2.9 cm^2 per year, and after adjusting for abdominal SAT the growth rate remained significant at 5.2±2.2 cm^2 per year.[17] However, as age increased, the growth in VAT slowed down.[17]

Age contributed 7.3% to the variance in VAT in 7–16-year-old white and Hispanic youth.[27] Over a 2-year period in 11–13-year-olds, boys increased IAT by 69% and increased from 0.31 to 0.39 in abdominal IAT-to-SAT ratio.[28] Girls increased 48% in IAT with a reduction in abdominal IAT-to-SAT ratio from 0.39 to 0.35.[28] One cross-sectional study adjusted for total AT and ethnicity, and demonstrated a decline in VAT as females went through adolescence, in contrast to males where VAT grew larger after age 12.[25]

In summary, VAT is present at birth and increases throughout childhood and adolescence, independent of growth in TBF or SAT. VAT growth appears constant throughout prepubertal ages (4–10 years)[26] but group differences in VAT growth emerge during the peripubertal and postpubertal ages.[27]

Subcutaneous adipose tissue

SAT increases as children age,[25] and age contributed 11% of the variance in SAT in a sample of 7–16-year-old Hispanic and white children.[27] In the first year of life, SAT composes the majority of TBF, varying between 89.0 to 92.3% of TBF [29] and 15.9 to 27.8% of total body weight.[11] Abdominal SAT is slightly lower, averaging 0.11±0.06 l in eight white newborn infants but still accounting for 12.2% of total body weight.[11] Annual observations over 3–5 years in 138 children (age 8.1±1.6 years) demonstrated that abdominal SAT grew 32.6±10.7 cm^2 per year.[17] Once adjusted for TBF, however, the growth rate was no longer significant. The authors conjecture that SAT is deposited in other areas than abdominally during this period in childhood.[17]

INFLUENCE OF SEX

Total body fat

Cross-sectional and longitudinal studies indicate that girls have more TBF than boys throughout childhood and adolescence (Table 1). This has been demonstrated in a longitudinal underwater weighing study in 8–20-year-olds[9] and in DXA cross-sectional studies of 7–17-year-olds in the US[30,31] and 6–18-year-olds in China,[32] among others. A cross-sectional study of 265 4–26-year-olds revealed that DXA-measured %BF was higher in females compared with males at all ages, and %BF increased for females throughout this period but not for males.[33] A contributing factor to sex differences in TBF is the higher amount of extremity BF in girls, as demonstrated in US children and adolescents aged 5–18

years.[34,35] Girls also have higher %BF by age 5, and this sex difference continues to increase until 18 years of age.[36] One exception is a study of 194 boys and 96 girls aged 6–15 years, in which CT-measured %BF was not different among girls and boys, though this was in a sample of obese children where sex differences may be attenuated.[37]

Sex differences in body fat emerge at specific developmental periods. At infancy, there is little documented sex difference in TBF. Female infants tend to have 50 g more DXA-derived TBF at birth than male infants, yet this 1.5% difference is within the coefficient of variation, and thus may not be detected in small sample sizes.[11] For instance, there were no sex differences in TBF in a cohort of eight white infants.[11] However, male infants tend to be longer in stature and have more lean mass during the first year of life,[38] which may contribute to sex differences in %BF.

Little MRI or CT data are available on sex differences during early childhood. A multi-component study calculating TBF from water, potassium and bone content found that TBF did not differ by sex during 0 to 24 months, except at 6 and 9 months at which point girls had higher %BF than boys.[15] In prepubertal children, girls typically have more TBF than boys. A CT study of 43 boys and 58 girls in the US aged approximately 7 years demonstrated that girls had more TBF.[26] African American 4–10-year-old girls had higher TBF and %BF (measured by DXA) than boys,[39] and Italian 3–11-year-old girls had more TBF than boys based on estimated fat mass from skinfold measurements.[40] However, not all studies demonstrate sex differences in TBF before puberty. A multi-year longitudinal study of American boys and girls aged 8.1±1.6 years found similar TBF.[17] There were no significant sex differences for TBF measured by bioelectrical resistance in a study of 4 boys and 12 girls aged 6.4±1.2 years in the US.[41] A study of 129 African American and white 10–12-year-olds indicated no difference in TBF measured by DXA across sexes, though boys had a bimodal distribution of TBF whereas girls' TBF was skewed to higher values.[42] Additionally, there were no sex differences in total abdominal fat measured by CT in 31 6–7-year-olds in the Netherlands.[43] Not controlling for other influences like age, maturational status and obesity status may account for the contradictory findings on sex differences, particularly in studies with small sample sizes.

During the pubertal period, females develop more TBF and fat deposited in the arms and legs, whereas males develop more total lean and muscle mass.[38] In a group of 678 children aged 8, 11 and 14 years, BMI and waist circumference (WC) increased similarly for both sexes, yet TBF increased in females and decreased in males.[18] In contrast, one study demonstrated no sex differences in TBF in a study of 160 US girls and boys aged 12–13 years.[44] Throughout adolescence after puberty, boys continue to primarily increase lean mass with little increase in TBF, as opposed to girls who tend to gain substantial TBF but little lean mass.[38] This sex divergence was also demonstrated in skinfold measurements collected in a representative sample of 5–18-year-olds in the US: girls increased in %BF throughout childhood and adolescence, whereas boys %BF peaked at age 11 and declined thereafter.[21]

Visceral adipose tissue

Findings related to sex differences in children and adolescents VAT are mixed. Many studies indicate males have more VAT than females throughout the ages of 5–25,[5,25,44,45] while others indicate no sex differences in VAT after adjustment for abdominal SAT in 4–10-year-olds.[26] Sex explained 1.8% of the variance in VAT in a study of 497 7–16-year-old prepubertal and pubertal boys and girls, and there was no sex difference in the abdominal VAT-to-SAT ratio.[27] However, boys had more VAT than girls in an MRI study of 12–13-year-old children, and the magnitude of the difference increased as WC increased.[44]

During childhood before puberty, boys may accumulate more VAT than girls. This was demonstrated in a study of 138 US girls and boys (mean age 8.1±1.6 years and followed for 3–5 years) in which VAT was higher in boys than in girls,[17] as well as in 290 Japanese children aged 6–15 years.[37] Despite similar %BF in 64 7–11-year-old obese boys and girls, boys had more VAT.[5] A study of 138 Hispanic and African American youth aged 13–25 showed that MRI-measured VAT was higher in boys than in girls.[45] Whereas IAT increased in peripubertal boys over a 2-year period (baseline mean 13 years old), the same decreased in girls.[28] In contrast, a CT study of prepubertal boys and girls (mean 13 years old) showed that IAAT was the same.[30]

During puberty, boys develop a more android shape by depositing more fat in the abdomen, whereas girls develop more TBF in general but deposit it in the hips and limbs forming a gynoid shape.[46] Boys' abdominal fat increases independently of total AT,[38] which was demonstrated in Australian 5–35-year-old males who had more abdominal fat than girls regardless of TBF.[47] In a US study (n = 160) of 12-year-olds, pubertal boys had higher VAT, WC, BMI and waist–hip ratio, even though pubertal girls had higher %BF.[44] VAT remained similar across the ages of 5–12 years, yet males had more VAT between 12 and 17 years, which marked pubertal onset for most.[25] DXA-derived waist fat and trunk fat adjusted for extremity fat was higher in boys than girls for those in late puberty in a sample of 5–29-year-olds, even though girls had more extremity and hip fat and more %BF.[48] Although 6–16-year-olds in Japan had no sex differences in VAT, older adolescent boys aged 16–20 had more VAT than their female counterparts.[49] Importantly, obesity increases android fat distribution in both sexes, thereby decreasing sex differences in body shape.[38]

Some studies demonstrate that girls have higher VAT than boys during adolescence. In a study of 160 12–14-year-olds, despite similar WC, girls had more IAAT compared with boys;[8] girls also were more sexually mature and had higher BMI and WC. Female adolescents aged ∼13–14 years had more VAT than males,[50] and also had higher BMIs. There was no sex difference in IAT (measured at the L4 lumbar level) in 16 obese adolescents (baseline age 12.8±1.4 years) measured over a 5-year period during pubertal attainment.[51] However, none of these studies controlled for TBF, and the fact that girls tend to have higher TBF may be driving the sex difference in these studies. More research is needed to elucidate reliable sex differences in VAT, and controlling for TBF is an important consideration.

Subcutaneous adipose tissue

SAT appears to be similar across sex before puberty. A study of 4 boys and 12 girls aged 6.4±1.2 years in the US showed no significant sex difference in abdominal SAT measured by skinfold thickness.[41] Similarly, abdominal SAT was the same in ~8-year-olds boys and girls in US,[17] in 6–7-year-olds in the Netherlands[43] and in 6–15-year-olds in Japan.[37] In contrast, 4–10-year-old girls had higher CT-measured abdominal SAT than boys,[26] African American 4–10-year-old girls had higher abdominal SAT measured by CT,[39] 8-year-old prepubertal girls had more abdominal SAT than boys in a US study using CT,[30] and girls had more whole-body SAT than boys in a sample of 147 5–17-year-old Caucasian, African American, Hispanic and Asian children.[25]

After puberty girls tend to accumulate more SAT than boys, as demonstrated in a 2-year study of 11–13-year-olds where girls increased abdominal SAT by 78% versus a 19% increase in boys.[28] Additionally, girls had more SAT in a CT study of 11–20-year-old Japanese adolescents,[49] and girls had more abdominal SAT in a sample of British 12–14-year-olds.[8] Whole-body SAT was also higher in pubertal adolescent girls in an MRI study of 5–17-year-olds in the US.[25] An exception was found in boys and girls with similar SAT in a CT study of 12–13-year-olds[44] and in a study of 138 US girls and boys aged 13–25;[45] however, neither analysis controlled for TBF.

INFLUENCE OF MATURATIONAL STATUS

Total body fat

Puberty involves simultaneous hormonal, biological and behavioral changes centered on sexual maturation, including the development of primary and secondary sexual characteristics.[52] Sexual maturation influences TBF accumulation. Whereas boys decrease in gynoid body fat in late puberty compared with early prepuberty, girls accumulate more gynoid body fat.[35] For instance, girls who are more sexually mature have more TBF than those less mature, whereas it is the opposite for boys.[53] In a DXA study of 920 5–18-year-old children grouped into pre-, early- and late-puberty based on breast or genitalia and pubic hair development, gynoid BF was lower in late pubertal compared with prepubertal boys, but there were no differences across pubertal stage for girls.[35] Skeletal maturation is also related to TBF, where rapidly maturing girls had more TBF and %BF than intermediate maturing girls, and rapidly maturing boys assessed from 8 to 20 years of age had higher TBF and %BF compared with slowly maturing boys.[9]

Visceral adipose tissue

Pubertal status explained 12.4% of the variance in VAT in a study of 7–16-year-olds.[27] In fact, failing to control for children and adolescents pubertal stage may contribute to inconsistencies in VAT comparisons across studies.[25] Obesity status may also alter the effects of puberty on VAT: in normal weight children, IAT typically decreases during puberty, whereas IAT typically stabilizes in obese children.[51] A longitudinal study of 16 obese male and female adolescents aged 12.8±1.4 years indicated that over a 4-year period, during which puberty was completed, IAT did not change, nor did relative body weight.[51]

Some results indicate that pubertal status did not significantly predict VAT in 5–17-year-olds, although chronological age did.[25] Children aged 7.7±1.6 years who remained prepubertal gained a similar amount of IAT (4.6 (SD 2.1) cm^2 per year) compared with those who began puberty (5.6 (SD 2.1) cm^2 per year).[26] In 10–15-year-old normal weight and obese youth, there was no difference in abdominal SAT-to-IAT ratio by pubertal status.[54] IAT remained constant over the 4 years (under 130 cm^2) though there was a 15–100 cm^2 range in individual variation of IAT.[54] Yet an MRI study of 170 British peripubertal 12–14-year-old youth demonstrated that pubertal status explained 3.7% of the variance in IAAT and was significantly related to IAAT in boys but not girls.[8] Pubertal status did not, however, significantly relate to the abdominal IAAT-SAT ratio in girls or boys.

During pubertal onset and directly following puberty, children and adolescents typically have low amounts of VAT compared with SAT. For instance, in one MRI study of 170 British 12–14-year-olds, less than 10% of total abdominal fat was IAAT.[8] Whereas fat distribution was consistent in pre- versus late-pubertal girls aged 5–18 years, boys gained more of an android fat distribution late in puberty.[35] Differences in VAT occurring in late puberty may be predominantly due to boys accumulation of VAT during this period versus smaller VAT growth in girls.[55]

Subcutaneous adipose tissue

Pubertal status contributed to 18.6% of the variance in abdominal SAT in a study of 497 7–16-year-old white and Hispanic children.[27] SAT appears to be relatively stable during puberty, as demonstrated in 170 12–14-year-olds in which there was no effect of pubertal status on abdominal SAT.[8] However, one study demonstrated an increase in abdominal SAT during and after puberty in 16 obese male and female adolescents over a 4-year period during pubertal onset from approximately age 12 through age 16.[51] Yet age, not pubertal status, significantly predicted SAT in a full-body MRI scan of 5–17-year-olds.[25]

INFLUENCE OF ETHNICITY

Total body fat

Ethnicity is a significant correlate of %BF, independent of BMI, sex, sexual maturation and distribution of fat, as demonstrated in a study of 201 white and African American 7–17-year-olds.[31] Ethnic differences are evident in TBF and fat patterning in children (Table 2). For instance, Asian 8–10-year-olds varied in TBF depending on country of origin and a marginal trend persisted in girls once adjusted for age and BMI.[56] White youth typically have more %BF than African American youth at any given BMI as observed in a sample of 7–17-year-olds;[31] however, the population of African American 2–17-year-old children experienced a steeper rise in the prevalence of obesity measured by BMI based on a 30-year period of successive cross-sectional data.[57] In a bioelectrical impedance study of white and African American 9–19-year-old girls, white girls had higher %BF between ages 9 and 12, whereas African American girls had a higher %BF at older ages.[58] These differences are attributed to minor fluctuations of %BF in girls between the ages of 9 and 12 years, followed

by a steeper incline in %BF in African American girls after age 12 that eclipsed white girls' %BF.

In a DXA study of 920 children, Asian girls had less gynoid fat compared with white and African American girls throughout pre-, early and late puberty during the ages of 5–18, and Asian boys had less gynoid fat during early and late puberty.[35] Similarly, Asian boys and girls had less extremity and gynoid fat compared with whites, whereas gynoid fat was similar between Asian and African American boys.[35]

Some studies indicate no ethnic differences in TBF: in a sample of 36 white and 65 African American prepubertal 4–10-year-old children, there were no ethnic differences in TBF or %BF despite differences in IAAT and abdominal SAT.[26] In a sample of 40 African American and white 7–10-year-old girls, there was no difference in DXA-measured TBF or %BF calculated by bioelectric impedance, although white girls had more fat deposited in the arm and chest.[59] Similarly, a sample of 40 African American and white 8–18-year-old overweight adolescent boys demonstrated no difference in MRI-measured total AT, even though African Americans had more whole-body SAT and less VAT.[60] One study demonstrated higher TBF in African Americans than whites at approximately age 8.[17] Obesity status may attenuate racial differences in TBF, demonstrated in a study of 55 obese adolescents (mean age 14–15 years) in which TBF and %BF did not differ among white, African American or Hispanic ethnic groups.[61]

Visceral adipose tissue

Racial/ethnic differences in VAT appear as early as infancy: in a comparison of 69 healthy Asian Indian and white European infants within 2 weeks of birth, Asian Indians had more VAT, despite having lower body mass, smaller head circumference and length, and less non-abdominal superficial SAT compared with the white Europeans.[62] In fact, ethnicity is a significant predictor of IAAT and can be used in a regression equation along with skinfold thickness to predict IAAT when DXA data are absent.[63]

Similarly, white youth have more VAT than African American youth at a given BMI.[64] In a study of 55 obese adolescents aged ~13 years, MRI-measured VAT was higher in white and Hispanic obese adolescents compared with African American obese adolescents,[61] and in a multi-ethnic sample of 118 obese adolescents aged 13–15, African Americans were less likely to be in the middle or upper tertile of VAT compared with white and Hispanic adolescents.[65] Despite similar total AT, 11–18-year-old overweight white boys had 50% more VAT than similarly aged overweight African American boys.[60] White children also accumulate IAAT relative to abdominal SAT at a 26% higher rate compared with African American children aged 4–10, demonstrated by a steeper regression line for IAAT to abdominal SAT in white compared with African American obese and non-obese children.[26] In a 3–5-year longitudinal study beginning at approximately age 8, white children had a steeper growth in VAT, growing on average 1.9±0.8 cm^2 per year in VAT more than African Americans did, with no ethnic difference in abdominal SAT or TBF growth.[17] A study of 20 African American and 20 white 7–10-year-old normal weight girls matched for BMI, bone age, chronological age, breast stage and socio-economic status, found that white girls had higher MRI-measured VAT and higher waist-to-thigh ratio compared with African

American girls.[59] For a given waist-to-height ratio, in a sample of 12-year-olds, white boys had more VAT and higher WC than African American boys, but there was no difference for girls.[44]

There were ethnic differences between 407 Hispanic and white 5–18-year-olds where Hispanics had higher VAT amounts than whites, but after correcting for abdominal SAT and BMI there was no difference in VAT.[27] Moreover, ethnicity explained just 2.1% of the variance in VAT and 5.9% of the variance in abdominal SAT.

Racial differences in VAT may be attenuated in obese children and adolescents. For instance, one study of 36 obese African American and white 6–18-year-olds found that CT-measured VAT did not differ by ethnicity after adjustment for age and pubertal stage.[66]

Subcutaneous adipose tissue

Although white youth tend to have higher WC on average, African American youth often have higher abdominal SAT and this accumulates faster at higher levels of WC.[44] African American 7–11-year-olds had more abdominal SAT and TBF than white youth, despite no ethnic difference in %BF or VAT.[5] Also, 11–18-year-old African American overweight boys had more whole-body SAT and specifically more leg and thigh SAT compared with overweight white boys, despite having similar total AT.[60] However, abdominal SAT did not differ by ethnicity in a study of 36 obese African American and white 6–18-year-olds,[66] and abdominal SAT was higher in white girls compared with African American girls in a 7–10-year-old sample matched for age, BMI, breast stage and socioeconomic status.[59] Ethnic differences are also seen at the beginning of life: in a study of 69 infants under 2 weeks old, Asian Indian infants had more deep abdominal SAT and superficial abdominal SAT than white European infants, even with lower body mass.[62]

HEALTH RISKS

The importance of where AT is stored and ensuing health risks was made evident in a comparison study of 28 obese adolescents on average 13 years old, of which half were insulin resistant and half were insulin sensitive.[67] Despite pairs being matched for age, sex, pubertal stage and body composition, obese insulin-resistant adolescents had higher VAT, indicating that VAT in particular was related to early formation of insulin resistance. One study of 118 obese adolescents demonstrated that as VAT increased, abdominal SAT decreased.[68] Interestingly, this adiposity profile of high VAT and low abdominal SAT had hepatic steatosis, insulin resistance and increased risk for metabolic syndrome. In a group of 14 obese adolescent girls aged 10–16, VAT but not BMI or waist–hip ratio highly correlated with cardiovascular risk factors including basal insulin, triglycerides and HDL cholesterol.[69]

Ultrasonography-measured VAT in 192 6–15-year-old obese children demonstrated that VAT (maximum preperitoneal fat thickness) was related to elevated systolic blood pressure, regardless of family history of hypertension.[70] MRI-measured VAT was related to adverse markers of insulin resistance syndrome in 81 obese African American and white 13–16-year-olds, independent of cardiovascular fitness.[71] In fact, VAT was a more powerful predictor than %BF (measured by DXA) for lipoproteins. An early review of the literature

determined that IAAT was related to fasting insulin, insulin secretion and sensitivity, triglyceride and cholesterol concentrations.[72] However, DXA-measured TBF was related to insulin sensitivity.

Sex influences

Sex differences in fat distribution may lead to different health outcomes. For instance, a study of 920 healthy US 5–18-year-olds revealed a relationship between trunk fat and higher fasting blood pressure in boys but not in girls.[34] This relationship remained in boys (African American, Asian, white) across all pubertal stages. Intra-abdominal obesity may only adversely influence blood pressure in males, whereas the metabolic and inflammatory responses to excess adiposity may be similar in boys and girls.[6] Obesity may attenuate sex differences in obesity-related health outcomes: in a separate study of children aged ~11 years-old, there was no difference in insulin resistance in obese boys and girls with similar TBF, %BF, abdominal SAT and VAT.[66]

Maturational status

Pubertal status may affect the relationship between AT and health outcomes. In children aged ~12 years whose amount of IAT remained constant across multiple measurements, IAT was related to insulin glucose metabolism after puberty only, but there was no relationship between IAT and insulin or glucose before puberty.[51] In peri- and postpubertal adolescents aged 10–15, IAT was significantly related to insulin and HDL cholesterol, demonstrating that adolescents past puberty have similar IAT-risk factor relationships as adults do.[54]

Ethnicity

The relationship between adiposity and metabolic risk may differ between African American and white youth.[64] Despite a lower VAT, African American 7–12-year-old youth tend to have higher risk for diabetes compared with white youth, as well as lower insulin sensitivity.[73] Glucose and insulin were correlated with abdominal SAT in African American girls only, and glucose/insulin were not correlated with VAT in either African American or white girls aged 7–10.[59] One study of 36 obese African American and white 6–18-year-olds found that VAT and abdominal SAT did not differ by ethnicity, nor did insulin levels or insulin resistance.[66] Further studies should investigate racial differences in how various adipose depots confer health risk.[59]

POTENTIAL MECHANISMS

It is important to discover the underlying mechanisms for the observed group differences in total and regional adiposity in children and adolescents, particularly to design clinical and public health interventions to prevent the accumulation of excess adiposity.

Biological and genetic factors

Genetic factors explain a significant proportion of the variance in total and depot-specific body fat.[74,75] However, the degree to which observed sex or ethnic differences in adiposity are explained by genetic differences is not well understood. The relative contributions of

genes versus the environment to the total phenotypic variance in BMI may differ between white and African American children;[76] however, little research exists on the differential effects of specific genetic markers for obesity in different ethnic groups in childhood.[77] The determination of genetic influences on obesity in different ethnic groups is a research priority.

Pubertal changes including insulin-sensitivity change,[53] hormonal and endocrine factors,[46] and sex steroid hormones like estrogen[38] relate to body composition changes. Body composition may differ based on growth spurts and peak height velocity.[78] The earlier that the adiposity rebound occurs in a child's life, the more likely that child is to become overweight.[16]

Current level of adiposity may determine the location of subsequent adiposity accumulation: differences between obese and non-obese children are predominantly found in the abdominal SAT compartment, although obese children also have more IAAT.[79] The difference in SAT by adiposity status may be from continued expansion of the SAT depot compared to a plateau of IAT, as demonstrated in obese 12-year-old adolescents over a 4-year longitudinal study.[51] Obesity also attenuates group differences in adiposity and fat. Ethnic differences between obese white and black 6–18-year-olds were only found for the SAT depot but not for VAT,[66] and no ethnic differences were observed in TBF or %BF in obese 13–14-year-olds.[61] One explanation may be that obesity promotes central fat distribution in an android pattern regardless of sex, ethnicity or maturational status.[38] Further research should examine how obesity status diminishes group differences that are otherwise apparent in non-obese children.

Behavior and lifestyle factors

Though the literature is sparse, lifestyle factors including physical activity and nutrition may impact TBF and depot-specific adiposity,[55] and there may be group differences that influence these daily behaviors. In a study of 42 8-year-old children, after controlling for TBF, higher amounts of physical activity measured by accelerometry was related to lower VAT, but not SAT.[80] VAT measured by MRI was inversely related to aerobic fitness measured by peak VO_2 consumption during a treadmill test in 30 male and 22 female adolescents aged ∼13.[50] A sedentary lifestyle may promote excess adipose accumulation. For instance, screen-time including watching television or movies predicted an increase in %BF measured by DXA in 661 healthy African American and white 14–18-year-olds.[81]

Nutrition also affects AT accumulation, though the relationships between dietary intake and depot-specific adiposity in children is not well studied.[55] Increased energy intake from protein predicted higher %BF in a sample of white and African American 14–18-year-old adolescents, but increased fat consumption predicted higher %BF in whites only and not in African Americans.[81] Interestingly, once energy intake was controlled for in regression analyses, there was no longer a significant relationship between vigorous physical activity and %BF.[81]

Stress may also be related to abdominal fat.[82,83] Insulin and cortisol may promote lipid growth.[47] A cross-sectional study of 23 female peripubertal Hispanic girls aged 8–11-years-

old demonstrated that school-related life events were related to higher VAT and abdominal SAT for girls who had high cortisol awakening response, but not for those with lower cortisol levels.[82] This stress may derive from environmental factors, particularly socio-economic status, which is inversely related to TBF in children.[84]

CHALLENGES AND FUTURE DIRECTIONS

Childhood and adolescence is a time of rapid growth, and maturational status is difficult to quantify in children and adolescents because pubertal stage, biological development, skeletal growth and somatic growth increase at different rates for different children and vary by chronological age[78] and pubertal stage.[55] Most studies are limited to cross-sectional analyses, and longitudinal analyses of the maturation of AT across the pediatric age range and pubertal stages of development are needed.[55] AT can change quickly and dramatically, and even though the total mass of AT may remain constant, the distribution of the fat may change particularly in puberty.[85] These developmental changes demonstrate the need for whole-body MRI measured by multiple slices so that fat lost at one site may be detected as fat gained at another site.[85]

Owing to the cost and resources required, most imaging studies published to date are typically limited by small sample sizes that are not necessarily representative of populations.[55] Population-based data on depot-specific AT in children and adolescents is virtually nonexistent; thus efforts should be made to include imaging methods in large-scale studies. Further, an urgent research priority is to determine the best anthropometric measurements of total and depot-specific body fat in children, such that better measures can be incorporated into epidemiological studies.[8]

Choosing the best protocols for current imaging instruments remains an urgent need, particularly in the pediatric population. Reliability and validity across imaging measures of adiposity should be established. Errors related to slice gap and number must be overcome, and methodologies need to maximize accuracy while minimizing the burden to the participant. The measurement methodology including instrument and measurement site may alter results, particularly considering group differences in fat patterning. For example, the L4–L5 intervertebral region of the spine is predominantly used in MRI studies to measure abdominal adiposity, but it is unknown if this slice provides the most accurate estimate of abdominal adiposity in children. A single MRI slice may not adequately provide a reference standard to measure total abdominal adiposity, meaning that multiple slices are needed. Ethnic-specific MRI measurement sites of VAT have been recommended in adolescents to best predict total VAT and risk for the metabolic syndrome.[86] Understanding which specific depots and regions of fat yield the most harm is necessary to tailor physical activity and weight-reduction efforts.

Moving beyond the study of IAT and VAT to examine organ-specific fat deposits, such as liver fat and intramyocellular lipid content, warrants further research. Ectopic fat deposition in organs and other tissues may better explain ethnic differences in health risks.[87] Among obese adolescents, African Americans did not have sufficient liver fat to be detected, whereas white and Hispanic adolescents had over twice as much liver fat as considered

normal.[61] Hispanic adolescents had higher liver fat and intramyocellular lipid content than both African American and white adolescents, even at similar weight and age. Moreover, ethnicity contributed 10% of the difference in liver fat and intramyocellular lipid, independent of age, gender or %BF.[61] Interestingly, in a multi-ethnic sample of 118 obese adolescents, at higher levels of VAT adolescents had less %BF and SAT and more hepatic fat, indicating that the excess amount of AT was being deposited in the visceral area, particularly in the liver.[65]

CONCLUSIONS

TBF and depot-specific AT influence cardiometabolic health risks in children and adolescents. Understanding the age, sex, maturational status and ethnic differences in TBF, VAT and SAT can improve prevention and treatment efforts, particularly if health risks are linked to these group differences. Future research should examine longitudinal changes of adiposity over time in representative samples of youth in order to generalize to the entire pediatric population.

Acknowledgments

PTK is supported, in part, by the Louisiana Public Facilities Authority Endowed Chair in Nutrition. AES is funded, in part, by an NIH National Research Service Award.

REFERENCES

1. Krebs NF, Jacobson MS. Academy of Pediatrics Committee on Nutrition. Prevention of pediatric overweight and obesity. Pediatrics. 2003; 112:424–430. [PubMed: 12897303]
2. Reilly JJ, Kelly J. Long-term impact of overweight and obesity in childhood and adolescence on morbidity and premature mortality in adulthood: Systematic review. Int J Obes. 2011; 35:891–898.
3. Shen W, Wang Z, Punyanita M, Lei J, Sinav A, Kral JG, et al. Adipose tissue quantification by imaging methods: a proposed classification. Obesity. 2003; 11:5–16.
4. Snyder, WM.; Cook, MJ.; Nasset, ES.; Karhausen, LR.; Howells, GP.; Tipson, IH. Report of the Task Group on the Reference Man. Oxford: Paergamon Press; 1984.
5. Owens S, Gutin B, Ferguson M, Allison J, Karp W, Le NA. Visceral adipose tissue and cardiovascular risk factors in obese children. J Pediatrics. 1998; 133:41–45.
6. Syme C, Abrahamowicz M, Leonard GT, Perron M, Pitoit A, Qui X, et al. Intra-abdominal adiposity and individual components of the metabolic syndrome in adolescence: sex differences and underlying mechanisms. Arch Pediatrics Adolescent Med. 2008; 162:453–461.
7. Sopher, A.; Shen, W.; Pietrobelli, A. Pediatric body composition methods. In: Heymsfield, SB.; Lohman, TG.; Wang, Z.; Going, SB., editors. Human Body Composition. 2nd edn. Champaign, IL: Human Kinetics; 2005.
8. Benfield LL, Fox KR, Peters DM, Blake H, Rogers I, Grant C, et al. Magnetic resonance imaging of abdominal adiposity in a large cohort of British children. Int J Obes. 2008; 32:91–99.
9. Guo SS, Chumlea WC, Roche AF, Siervogel RM. Age- and maturity-related changes in body composition during adolescence into adulthood: The Fels Longitudinal Study. Int J Obes. 1997; 21:1167–1175.
10. Deans HE, Smith FW, Lloyd DJ, Law AN, Sutherland HW. Fetal fat measurement by magnetic resonance imaging. Br J Radiol. 1989; 62:603–607. [PubMed: 2758247]
11. Harrington TAM, Thomas EL, Modi N, Frost G, Coutts GA, Bell JD. Fast and reproducible method for the direct quantitation of adipose tissue in newborn infants. Lipids. 2002; 37:95–100. [PubMed: 11878317]

12. De Bruin NC, van Velthoven KAM, de Ridder M, Stijnen T, Juttmann RE, Degenhart HJ, et al. Standards for total body fat and fat-free mass in infants. Arch Dis Child. 1996; 74:386–399. [PubMed: 8669953]
13. Ellis KJ, Abrams SA, Wong WW. Body composition of a young, multiethnic female population. Am J Clin Nutr. 1997; 65:724–731. [PubMed: 9062521]
14. Ellis KJ. Body composition of a young, multiethnic male population. Am J Clin Nutr. 1997; 66:1323–1331. [PubMed: 9394682]
15. Butte NF, Hopkinson JM, Wong WW, Smith EO, Ellis KJ. Body composition during the first 2 years of life: an updated reference. Pediatric Research. 2000; 47:578–585. [PubMed: 10813580]
16. Freedman DS, Kettel Khan L, Serdula MK, Srinivasan SR, Berenson GS. BMI rebound, childhood height and obesity among adults: the Bogalusa Heart Study. Int J Obes. 2001; 25:543–549.
17. Huang TTK, Johnson MS, Figueroa-Colon R, Dwyer JH, Goran MI. Growth of visceral fat, subcutaneous abdominal fat, and total body fat in children. Obesity Res. 2001; 9:283–289.
18. Dai S, Labarthe DR, Grunbaum JA, Harrist RB, Mueller WH. Longitudinal analysis of changes in indices of obesity from age 8 years to age 18 years: Project HeartBeat! Am J Epidemiol. 2002; 156:720–729. [PubMed: 12370160]
19. Lloyd T, Chinchilli VM, Eggli DF, Rollings N, Kulin HE. Body composition development of adolescent white females: The Penn State Young Women's Health Study. Arch Pediatr Adolesc Med. 1998; 152:998–1002. [PubMed: 9790610]
20. Rolland-Cachera MF, Cole TJ, Sempe M, Tichet J, Rossignol C, Charraud A. Body mass index variations: Centiles from birth to 87 years. Eur J Clin Nutr. 1991; 45:13–21. [PubMed: 1855495]
21. Laurson KR, Eisenmann JC, Welk GJ. Body fat percentile curves for U.S. children and adolescents. Am J Preventive Med. 2011; 41(Suppl 2):S87–S92.
22. Harrington TAM, Thomas EL, Frost G, Modi N, Bell JD. Distribution of adipose tissue in the newborn. Pediatric Res. 2004; 55:437–441.
23. Ibáñez L, Lopez-Bermejo A, Suárez L, Marcos MV, Díaz M, de Zegher F. Visceral adiposity without overweight in children born small for gestational age. J Clin Endocrinol Metab. 2008; 93:2079–2083. [PubMed: 18334595]
24. Ibáñez L, Suárez L, Lopez-Bermejo A, Díaz M, Valls C, de Zegher F. Early development of visceral fat excess after spontaneou catch-up growth in children with low birth weight. J Clin Endocrinol Metab. 2008; 93:925–928. [PubMed: 18089700]
25. Shen W, Punyanitya M, Silva AM, Chen J, Gallagher D, Sardinha LB, et al. Sexual dimorphism of adipose tissue distribution across the lifespan: a cross-sectional whole-body magnetic resonance imaging study. Nutr Metab. 2009; 6:17.
26. Goran M, Nagy T, Treuth M, Trowbridge C, Dezenberg C, McGloin A, et al. Visceral fat in white and African American prepubertal children. Am J Clin Nutr. 1997; 65:1703–1708. [PubMed: 9174463]
27. Brambilla P, Bedogni G, Moreno LA, Goran MI, Gutin B, Fox KR, et al. Cross-validation of anthropometry against magnetic resonance imaging for the assessment of visceral and subcutaneous adipose tissue in children. Int J Obes. 2006; 30:23–30.
28. Fox KR, Peters DM, Sharpe P, Bell M. Assessment of abdominal fat development in young adolescents using magnetic resonance imaging. Int J Obes Relat Metab Disord. 2000; 24:1653–1659. [PubMed: 11126220]
29. Olhager E, Thomas KA, Wigstrom L, Forsum E. Description and evaluation of a method based on magnetic resonance imaging to estimate adipose tissue volume and total body fat in infants. Pediatr Res. 1998; 44:572–577. [PubMed: 9773848]
30. Herd S, Gower B, Dashti N, Goran M. Body fat, fat distribution and serum lipids, lipoproteins and apolipoproteins in African-American and Caucasian-American prepubertal children. Int J Obes. 2001; 25:198–204.
31. Daniels S, Khoury P, Morrison J. The utility of body mass index as a measure of body fatness in children and adolescents: differences by race and gender. Pediatrics. 1997; 99:804–807. [PubMed: 9164773]

32. Wang H, Story RE, Venners SA, Wang B, Yang J, Li Z, et al. Patterns and interrelationships of body-fat measures among rural Chinese children aged 6 to 18 years. Pediatrics. 2007; e120:e194–e101.
33. Ogle G, Allen J, Humphries I, Lu PW, Briody JN, Morley K, et al. Body-composition assessment by dual-energy X-ray absorptiometry in subjects aged 4–26 y. Am J Clin Nutr. 1995; 61:746–753. [PubMed: 7702015]
34. He Q, Horlick M, Thornton J, Wang J, Pierson RN Jr. Heshka S, et al. Sex and race differences in fat distribution among Asian, African-American, and Caucasian prepubertal children. J Clin Endocrinol Metab. 2002; 87:2164–2170. [PubMed: 11994359]
35. He Q, Horlick M, Thornton J, Wang J, Pierson RN, Heshka S, et al. Sex-specific fat distribution is not linear across pubertal groups in a multiethnic study. Obes Res. 2004; 12:725–733. [PubMed: 15090643]
36. Shaw NJ, Crabtree NJ, Kibirige MS, Fordham JN. Ethnic and gender differences in body fat in British schoolchildren as measured by DXA. Arch Dis Child. 2007; 92:872–875. [PubMed: 17522163]
37. Asayama K, Hayashibe H, Endo A, Okada T, Hara M, Masuda H, et al. Threshold values of visceral fat and waist girth in Japanese obese children. Pediatrics Int. 2005; 47:498–504.
38. Wells JCK. Sexual dimorphism of body composition. Best Practice Res Clin Endo-crinol Metab. 2007; 21:415–430.
39. Ku CY, Gower BA, Nagy TR, Goran MI. Relationship between dietary fat, body fat, and serum lipid profile in prepubertal children. Obes Res. 1998; 6:400–407. [PubMed: 9845229]
40. Maffeis C, Pietrobelli A, Grezzani A, Provera S, Tato L. Waist circumference and cardiovascular risk factors in prepubertal children. Obesity Res. 2001; 9:179–187.
41. Goran MI, Kaskoun MC, Shuman WP. Intra-abdominal adipose tissue in young children. Int J Obes. 1995; 19:279–283.
42. Bray GA, DeLany JP, Harsha DW, Volaufova J, Champagne CC. Evaluation of body fat in fatter and leaner 10-y-old African American and white children: the Baton Rouge Children's Study. Am J Clin Nutr. 2001; 73:687–702. [PubMed: 11273842]
43. Liem ET, Rolfe EDL, L'Abée C, Sauer PJJ, Ong KK, Stolk RP. Measuring abdominal adiposity in 6 to 7-year-old children. Eur J Clin Nutr. 2009; 63:835–841. [PubMed: 19127281]
44. Lee S, Kuk JL, Hannon TS, Arslanian SA. Race and gender differences in the relationships between anthropometrics and abdominal fat in youth. Obesity. 2008; 16:1066–1071. [PubMed: 18356853]
45. Le KA, Ventura EE, Fisher JQ, Davis JN, Weigensberg MJ, Punyanitya M, et al. Ethnic differences in pancreatic fat accumulation and its relationship withother fat depots and inflammatory markers. Diabetes Care. 2011; 34:485–490. [PubMed: 21270204]
46. Loomba-Albrecht LA, Styne DM. Effect of puberty on body composition. Curr Opin Endocrinol Diabetes Obesity. 2009; 16:10–15.
47. Cowell CT, Briody J, Lloyd-Jones S, Smith C, Moore B, Howman-Giles R. Fat distribution in children and adolescents - the influence of sex and hormones. Hormone Res Pediatrics. 1997; 48(Suppl 5):93–100.
48. Taylor RW, Grant AM, Williams SM, Goulding A. Sex differences in regional body fat distribution from pre- to postpuberty. Obesity. 2010; 18:1410–1416. [PubMed: 19893501]
49. Satake E, Nakagawa Y, Kubota A, Saegusa H, Sano S-i Ohzeki T. Age and sex differences in fat distribution in non-obese Japanese children. J Pediatric Endocrinol Metab. 2010; 23:873–878.
50. Winsley R, Armstrong N, Middlebrooke A, Ramos-Ibanez N, Williams C. Aerobic fitness and visceral adipose tissue in children. Acta Paediatrica. 2006; 95:1435–1438. [PubMed: 17062473]
51. Brambilla P, Manzoni P, Agostini G, Beccaria L, Ruotolo G, Sironi S, et al. Persisting obesity starting before puberty is associated with stable intraabdominal fat during adolescence. Int J Obes. 1999; 23:299–303.
52. Kirchengast S, Angelika G. Body composition characteristics during puberty in girls and boys from Eastern Austria. Int J of Anthropology. 2003; 18:139–151.

53. Travers SH, Jeffers BW, Bloch CA, Hill JO, Eckel RH. Gender and Tanner stage differences in body composition and insulin sensitivity in early pubertal children. J Clin Endocr Metab. 1995; 80:172–178. [PubMed: 7829608]

54. Brambilla P, Manzoni P, Sironi S, Del Maschio A, di Natale B, Chiumello G. Peripheral and abdominal adiposity in childhood obesity. Int J Obes Relat Metab Disord. 1994; 18:795–800. [PubMed: 7894517]

55. Suliga E. Visceral adipose tissue in children and adolescents: a review. Nutrition Res Rev. 2009; 22:137–147. [PubMed: 19737436]

56. Liu A, Byrne N, Kagawa M, Ma G, Kijboonchoo K, Nasreddine L, et al. Ethnic differences in body fat distribution among Asian pre-pubertal children: a cross-sectional multicenter study. BMC Public Health. 2011; 11:500. [PubMed: 21703012]

57. Freedman DS, Khan LK, Serdula MK, Ogden CL, Dietz WH. Racial and ethnic differences in secular trends for childhood BMI, weight, and height. Obesity. 2006; 14:301–308. [PubMed: 16571857]

58. Morrison JA, Barton BA, Obarzanek E, Crawford PB, Guo SS, Schreiber GB. Racial differences in the sums of skinfolds and percentage of body fat estimated from impedance in black and white girls, 9 to 19 years of age: The National Heart, Lung, and Blood Institute Growth and Health Study. Obesity Res. 2001; 9:297–305.

59. Yanovski JA, Yanovski SZ, Filmer KM, Hubbard VS, Avila N, Lewis B, et al. Differences in body composition of black and white girls. Am J Clin Nutr. 1996; 64:833–839. [PubMed: 8942404]

60. Lee S, Kim Y, Kuk JL, Boada FE, Arslanian S. Whole-body MRI and ethnic differences in adipose tissue and skeletal muscle distribution in overweight black and white adolescent boys. J Obesity. 2011; 2011:159373.

61. Liska D, Dufour S, Zern TL, Taksali S, Cali AMG, Dziura J, et al. Interethnic differences in muscle, liver and abdominal fat partitioning in obese adolescents. PLoS One. 2007; 2:e569. [PubMed: 17593968]

62. Modi N, Thomas EL, Uthaya SN, Umranikar S, Bell JD, Yajnik C. Whole body magnetic resonance imaging of healthy newborn infants demonstrates increased central adiposity in Asian Indians. Pediatr Res. 2009; 65:584–587. [PubMed: 19190541]

63. Goran M, Gower BA, Treuth MS, Nagy TR. Prediction of intra-abdominal and subcutaneous abdominal adipose tissue in healthy pre-pubertal children. Int J Obes. 1998; 22:549–558.

64. Bacha F, Saad R, Gungor N, Janosky J, Arslanian SA. Obesity, regional fat distribution, and Syndrome X in obese black versus white adolescents: race differential in diabetogenic and atherogenic risk factors. J Clin Endocrinol Metab. 2003; 88:2534–2540. [PubMed: 12788850]

65. Taksali SE, Caprio S, Dziura J, Dufour S, Cali AMG, Goodman TR, et al. High visceral and low abdominal subcutaneous fat stores in the obese adolescent: a determinant of an adverse metabolic phenotype. Diabetes. 2007; 57:367–371. [PubMed: 17977954]

66. Tershakovec AM, Kuppler KM, Zemel BS, Katz L, Weinzimer S, Harty MP, et al. Body composition and metabolic factors in obese children and adolescents. Int J Obes. 2003; 27:19–24.

67. Weiss R, Taksali SE, Dufour S, Yeckel CW, Papademetris X, Cline G, et al. The "obese insulin-sensitive" adolescent: importance of adiponectin and lipid partitioning. J Clin Endocrinol Metabolism. 2005; 90:3731–3737.

68. Cali AM, Caprio S. Ectopic fat deposition and the metabolic syndrome in obese children and adolescents. Hormone Res Pediatrics. 2009; 71(Suppl 1):2–7.

69. Caprio S, Hyman LD, McCarthy S, Lange R, Bronson M, Tamborlane WV. Fat distribution and cardiovascular risk factors in obese adolescent girls: Importance of the intraabdominal fat depot. Am J Clin Nutr. 1996; 64:12–17. [PubMed: 8669407]

70. Nishina M, Kikuchi T, Yamazaki H, Kameda K, Hiura M, Uchiyama M. Relationship among systolic blood pressure, serum insulin and leptin, and visceral fat accumulation in obese children. Hypertens Res. 2003; 26:281–288. [PubMed: 12733695]

71. Owens S, Gutin B, Barbeau P, Litaker M, Allison J, Humphries M, et al. Visceral adipose tissue and markers of the insulin resistance syndrome in obese black and white teenagers. Obesity Res. 2000; 8:287–293.

72. Goran MI, Gower BA. Relation between visceral fat and disease risk in children and adolescents. Am J Clin Nutr. 1999; 70:149S–1565.

73. Goran MI, Bergman RN, Gower BA. Influence of total vs. visceral fat on insulin action and secretion in African American and White children. Obesity Res. 2001; 9:423–431.

74. Comuzzie AG, Higgins PB, Voruganti S, Cole S. Cutting the fat: the genetic dissection of body weight. Prog Mol Biol Transl Sci. 2010; 94:197–212. [PubMed: 21036326]

75. Katzmarzyk PT, Perusse L, Bouchard C. Genetics of abdominal visceral fat levels. Am J Hum Biol. 1999; 11:225–235. [PubMed: 11533946]

76. Katzmarzyk PT, Mahaney MC, Blangero J, Quek JJ, Malina RM. Potential effects of ethnicity in genetic and environmental sources of variability in the stature, mass, and body mass index of children. Hum Biol. 1999; 71:977–987. [PubMed: 10592687]

77. Klimentidis YC, Chen G-B, Lopez-Alarcon M, Harris JJ, Duarte CW, Fernandez JR. Associations of obesity genes with obesity-related outcomes in multiethnic children. Arch Med Res. 2011; 42:509–514. [PubMed: 22051089]

78. Malina RM, Koziel S, Bielicki T. Variation in subcutaneous adipose tissue distribution associated with age, sex, maturation. Am J Hum Biol. 1999; 11:189–200. [PubMed: 11533943]

79. Fox KR, Peters DM, Armstrong N, Sharpe P, Bell M. Abdominal fat deposition in 11-year-old children. Int J Obes Relat Metab Disord. 1993; 17:11–16. [PubMed: 8383635]

80. Saelens BE, Seeley RJ, van Schaick K, Donnelly LF, O'Brien KJ. Visceral abdominal fat is correlated with whole-body fat and physical activity among 8-y-old children at risk of obesity. Am J Clin Nutr. 2007; 85:46–53. [PubMed: 17209176]

81. Stallmann-Jorgensen IS, Gutin B, Hatfield-Laube JL, Humphries MC, Johnson MH, Barbeau P. General and visceral adiposity in black and white adolescents and their relation with reported physical activity and diet. Int J Obes. 2007; 31:622–629.

82. Donoho CJ, Weigensberg MJ, Emken BA, Hsu J-W, Spruijt-Metz D. Stress and abdominal fat: preliminary evidence of moderation by the cortisol awakening response in Hispanic peripubertal girls. Obesity. 2010; 19:946–952. [PubMed: 21127479]

83. Kyrou I, Chrousos GP, Tsigos C. Stress visceral obesity, and metabolic complications. Ann NY Acad Sci. 2006; 1083:77–110. [PubMed: 17148735]

84. Rizzo NS, Ruiz JR, Hurtig-Wennlof A, Kwak L, Sjostrom M. Socioeconomic status and its association with objectively-measured total physical activity and body fat in children: The European Youth Heart Study. Int J Body Composit Res. 2010; 8:93–98.

85. Shen W, Liu H, Punyanitya M, Chen J, Heymsfield SB. Pediatric obesity pheno-typing by magnetic resonance methods. Curr Opin Clin Nutr Metab Care. 2005; 8:595–601. [PubMed: 16205458]

86. Lee S, Kuk JL, Kim Y, Arslanian S. Measurement site of visceral adipose tissue and prediction of metabolic syndrome in youth. Pediatr Diabetes. 2011; 12(pt2):250–257. [PubMed: 21129140]

87. D'Adamo E, Northrup V, Weiss R, Santoro N, Pierpont B, Savoye M, et al. Ethnic differences in lipoprotein subclasses in obese adolescents: importance of liver and intraabdominal fat accretion. Am J Clin Nutr. 2010; 92:500–508. [PubMed: 20573788]

88. Deurenberg P, Deurenberg-Yap M, Foo LF, Schmidt G, Wang J. Differences in body composition between Singapore Chinese, Beijing Chinese and Dutch children. Eur J Clin Nutr. 2003; 57:405–409. [PubMed: 12627175]

89. Gower BA, Nagy TR, Trowbridge CA, Dezenberg C, Goran MI. Fat distribution and insulin response in prepubertal African American and white children. Am J Clin Nutr. 1998; 67:821–827. [PubMed: 9583837]

90. Wong WW, Hergenroeder AC, Stuff JE, Butte NF, Smith EOB, Ellis KJ. Evaluating body fat in girls and female adolescents: advantages and disadvantages of dual-energy X-ray absorptiometry. Am J Clin Nutr. 2002; 76:384–389. [PubMed: 12145011]

Table 1

Sex differences in TBF and depot-specific adiposity in children and adolescents

Reference	*Country*	n *(boys, girls)*	*Age (y)*	*Instrument*	*TBF*	*VAT*	*Abdominal SAT*
47	Australia	169, 166	4–35	DXA	%BF: G>B		
31	US	100, 92	7–17	DXA	NS		
26	US	43, 58	7.7 ± 1.6	CT, DXA	G>B	IAAT: G>B	G>B
39	US	30, 36	4–10	CT, DXA	G>B		G> B
5	US	21, 43	7–11	MRI, DXA	NS	B>G	NS
51	US	8, 8	12.8 ± 1.4	MRI		IAT: NS	
71	US	26, 54	13–16	MRI, DXA	%BF: NS	NS	
42	US	65, 64	10–12	DXA	NS		
30	US	58, 43	AA: 8.3±1.4	CT, DXA	G>B	NS	G>B
			W: 8.6±1.2				
17	US	47, 91	8.1 ± 1.6	CT, DXA	NS	B>G	NS
			3–5 years longitudinal				
11	US	4, 4	<1.5 days	MRI	NS	NS	NS
88	Singapore, Beijing, the Netherlands	75, 75	7–12	DXA	NS		
66	US	15, 21	11.8 ± 0.5	CT, DXA	NS	NS	NS
37	Japan	194, 96	6–15	CT		B>G	NS
32	China	1328, 1165	6–18	DXA	G>B		
8	UK	74, 96	13.4 ±0.4	MRI		IAAT: G>B	G>B
			13.5 ±0.5				
44	US	84, 76	~12–13	CT, DXA	NS	B>G	NS
43	The Netherlands	14, 17	6–7	CT, DXA	NS	NS	NS
25	US	88, 59	5–17	MRI		NS (<12y)	G>B
						B>G (>12y)	
49	Japan	73, 57	6–20	CT		B>G (16–20 years)	G>B (11–20 years)
48	US	518, 491	5–29	DXA	G>B		
45	US	40, 98	13–25	MRI, DXA	%BF: G>B	B>G	NS

Abbreviations: %BF, percent body fat; B>G, boys significantly higher than girls; CT, computed tomography; DXA, dual-energy X-ray absorptiometry; G>B, girls significantly higher than boys; IAT, internal adipose tissue; IAAT, intra-abdominal adipose tissue; MRI, magnetic resonance imaging; NS, no significant difference between sexes; SAT, subcutaneous adipose tissue; TBF, total body fat; VAT, visceral adipose tissue.

Table 2

Ethnic differences in TBF and depot-specific adiposity in children and adolescents

Reference	*Country: ethnic groups*	**n**	*Age (y)*	*Instrument*	*TBF*	*VAT*	*Abdominal SAT*
59	US girls: AA, W	40	7–10	MRI, DXA	NS	W>AA	W>AA
31	US: AA, W	192	7–17	DXA	NS		
13	US girls: AA, Hisp, W	313	3–18	DXA	Hisp>W		
14	US boys: AA, Hisp, W	297	3–18	DXA	Hisp>W		
					Hisp>AA		
					W>AA		
26	US	101	7.7 ± 1.6	CT, DXA	NS	W>AA	W>AA
89	US: AA, W	73	5–10	CT, DXA	NS	NS	NS
39	US: AA, W	66	4–10	CT	NS	IAAT: W>AA	NS
5	US: AA, W	64	7–11	MRI, DXA	AA>W	NS	AA>W
71	US: AA, W	81	13–16	MRI, DXA	%BF: NS	W>AA	
42	US: AA, W	129	10–12	DXA	NS		
73	US: AA, W	119	8–11	CT, DXA	NS	NS	NS
30	US: AA, W	101	AA: 8.3±1.4	CT, DXA	NS	W>AA (adj. TBF)	W>AA (adj. TBF)
			W: 8.6±1.2				
17	US: AA, W	138	8.1±1.6 Longitudinal	CT, DXA	AA>W	NS	NS
90	US girls: AA, AsA, Hisp, W	141	13.0 ± 1.9	DXA	NS		
64	US: AA, W	50	AA: 13.4±0.3	CT, DXA	NS	W>AA	NS
			W: 13.3±0.4				
61	US: AA, Hisp, W	55	AA: 14.7±2.73	MRI, DXA	NS	W and Hisp>AA	NS
		obese	Hisp: 15.2±2.4				
			W: 14.6±1.84				
44	US: AA, W	160	~12–13	CT, DXA	NS	NS	NS
45	US: AA, Hisp	138	13–25	MRI	%BF:	Hisp>AA	NS
					Hisp>AA		
60	US: AA, W	40	11–18	MRI		W>AA	NS
							whole body: AA>W

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Abbreviations: %BF, percent body fat; AA, African American; adj. TBF, analyses were adjusted for total body fat; AsA, Asian American; CT, computed tomography; DXA, dual-energy X-ray absorptiometry; Hisp, Hispanic American, IAAT, intra-abdominal adipose tissue; MRI, magnetic resonance imaging; NS, no significant difference between ethnic groups; SAT, subcutaneous adipose tissue; TBF, total body fat; VAT, visceral adipose tissue; W, white.